THE THERMAL CONDUCTIVITY OF PURE WATER AND STANDARD SEA WATER AS A FUNCTION OF PRESSURE AND TEMPERATURE. PART III. STANDARD SEA WATER

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Naval Ship Research and Development Center
Annapolis, Maryland

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Report 3566

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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Md. 20034

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Part III - Standard Sea Water

by
V. John Castelli and E. M. Stanley

MATERIALS DEPARTMENT
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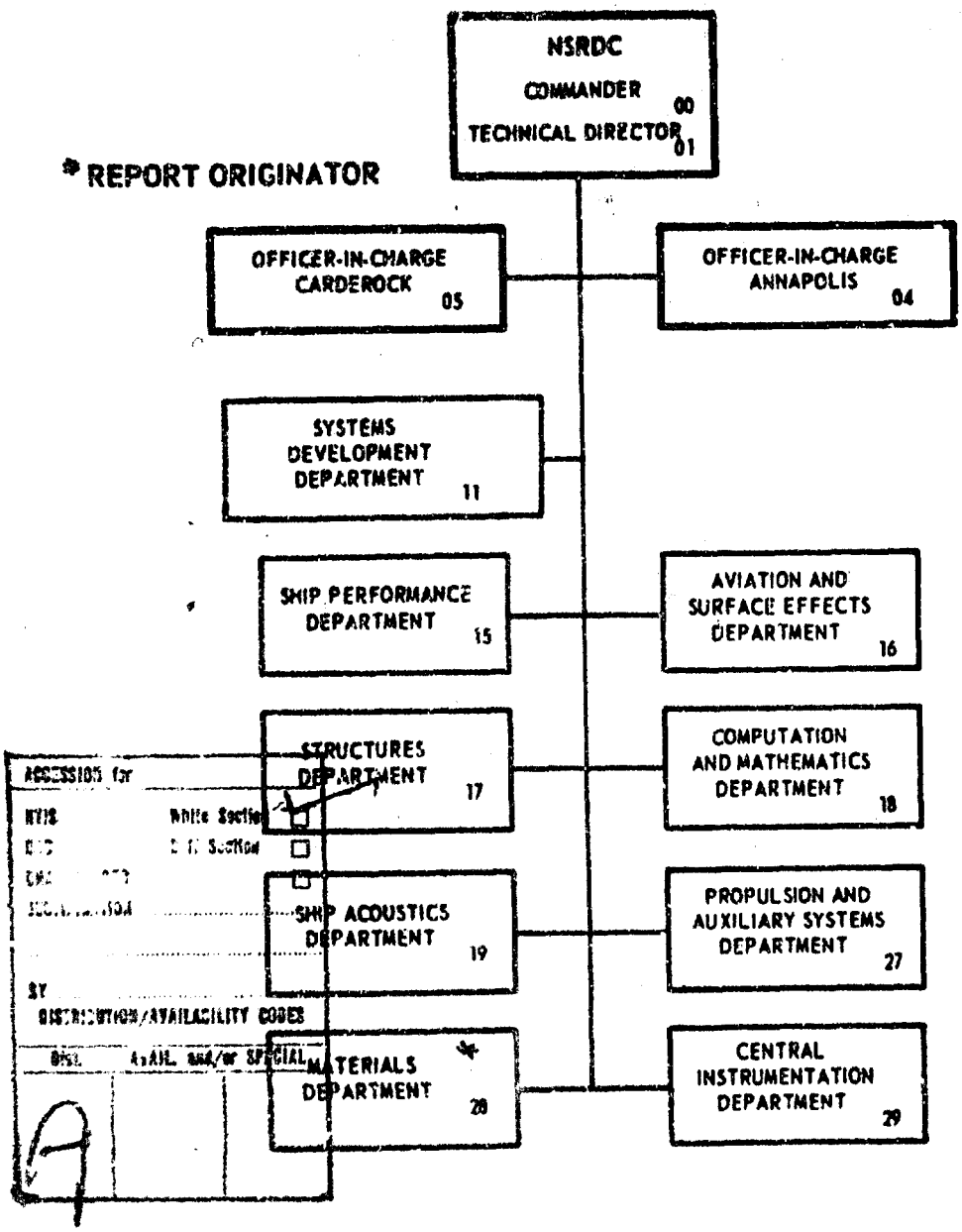

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INTRODUCTION

A continuing effort of oceanographic research at this activity is the determination of various chemical/physical properties of sea water as a function of pressure. Previous projects have included viscosity and refractive index measurements at pressure. The most recently completed project is the determination of thermal conductivity for sea water and pure water in the temperature range of 0° to 30° C* and the pressure range of 0 to 1400 bars. This is the third and last in the series of reports and describes the experimental setup and results of the experimental determinations of the thermal conductivity for standard sea water.

EXPERIMENTAL INVESTIGATIONS

Measurements of the thermal conductivity of standard sea water were conducted at temperatures of +1.82°, 10.23°, 20.22°, and 30.25° C and nominal pressures of 10, 200, 400, 600, 800, 1000, 1200, and 1400 bars.

The cleansing, filling, and setup procedures for the use of the special high-pressure experimental apparatus have been previously described.[1] The sea water used throughout this phase of the experiment was International Association of Physical Oceanography Standard Sea Water of Chlorinity 19.3705 ‰.

Using the newly redefined relationship between chlorinity and salinity given by Wooster, et al,[2] as

Salinity = 1.80655 Chlorinity

yields a value of 34.994 o/oo salinity for the water used in this experiment.

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*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

[1]Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

PRECISION, ACCURACY AND ERROR ANALYSIS

In these measurements, as previously, two distinct series were conducted with different thermocouple junctions. Each series consisted of at least three determinations of each data point and many determinations of selected "reference" data points, primarily at 10 bars pressure. In almost all cases, the data resultant from any particular series agreed to within 0.3% of the mean value. The reasons for this variation, as well as a discussion of the accuracy and a complete error analysis have been previously described.[3]

RESULTS

The corrected results of our determinations for standard sea water are listed in table 1, and are shown graphically in figure 1.

TABLE 1 - THERMAL CONDUCTIVITY (10^{-5} WATTS/CM-DEG) OF 34.994‰ STANDARD SEA WATER AS A FUNCTION OF TEMPERATURE AND PRESSURE

Pressure	Temperature, ° C							
	1.82		10.23		20.22		30.25	
	I	II	I	II	I	II	I	II
10	555.0	558.5	571.0	570.0	588.0	585.5	600.0	598.0
200	562.0	565.0	578.5	577.0	595.5	592.0	607.0	603.5
400	569.5	571.5	585.5	584.5	603.0	599.5	614.5	611.5
600	577.0	578.5	593.0	590.5	610.5	606.5	622.5	616.5
800	583.5	585.0	599.0	598.0	616.5	613.5	628.5	624.5
1000	590.0	591.5	607.0	604.5	624.5	619.5	636.0	631.5
1200	596.0	595.0	613.0	612.5	629.5	626.0	642.5	638.5
1400	602.0	601.5	619.5	617.5	636.0	632.5	649.0	645.5

I - Iron-Constantan Thermocouple Junction
II - Chromel-Constantan Thermocouple Junction

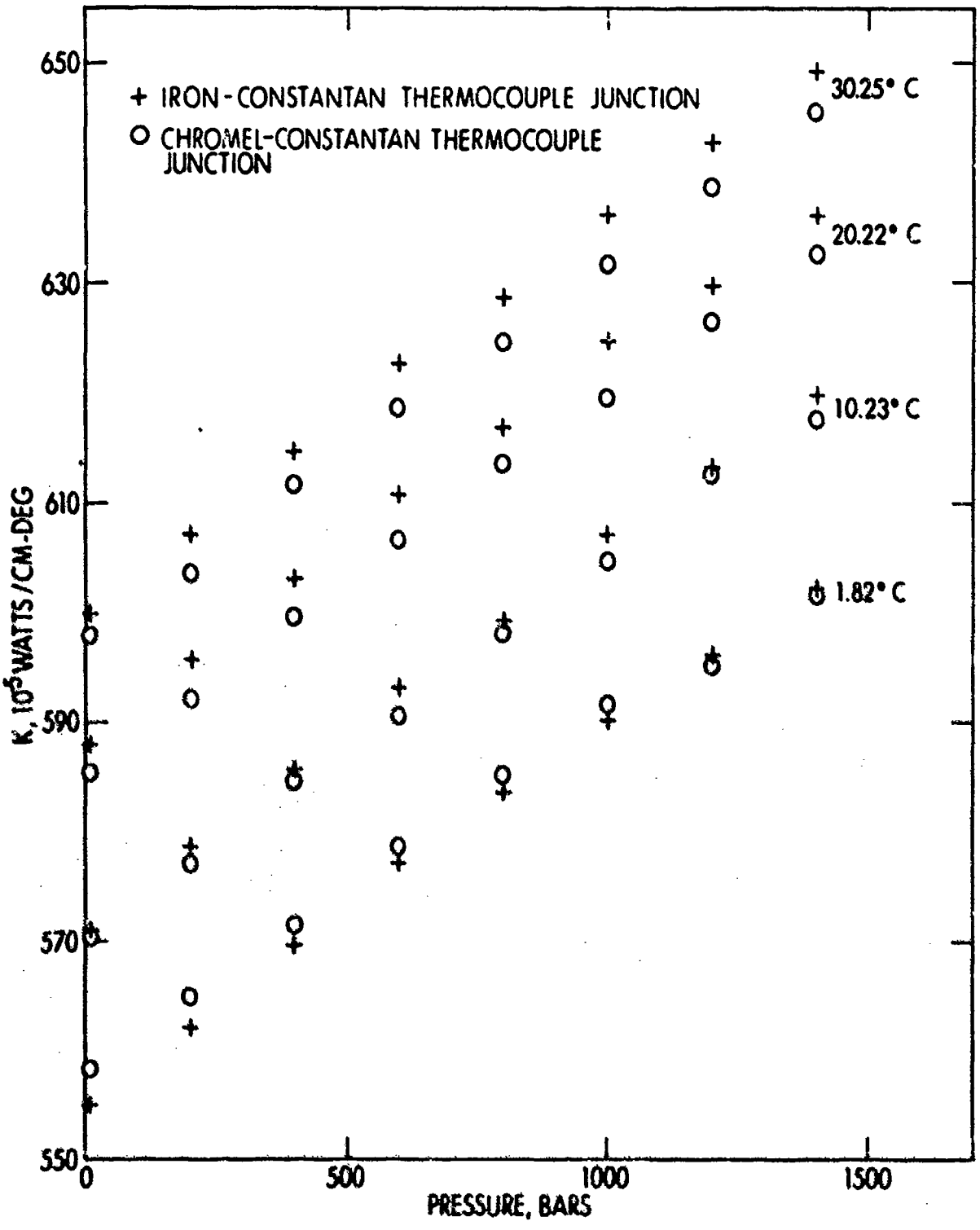

Figure 1 - Experimental Data for the Thermal Conductivity of Standard Sea Water as a Function of Pressure for Various Temperatures

The data reported can be represented as a function of temperature and pressure by the equation

$$K = 5.5286 \times 10^{-3} + 3.4025 \times 10^{-7} \; P + 1.8364 \times 10^{-5} T - 3.3058 \times 10^{-9} \; T^3 \qquad (1)$$

where:

K = thermal conductivity, watts/cm-deg

P = pressure, bars

T = temperature, ° C.

Values generated with this equation are listed in table 2 and are depicted graphically in figure 2. The equation yields values which have a standard error of $\pm 1.7 \times 10^{-5}$ watts/cm-deg, or ±0.28%, from the experimental data.

TABLE 2 - VALUES OF THE THERMAL CONDUCTIVITY OF STANDARD SEA WATER AS DETERMINED FROM EQUATION (1)

Pressure Bars	Temperature, ° C			
	0	10	20	30
Atmosphere	553.0	571.0	586.5	598.5
200	559.5	577.5	593.5	605.5
400	566.5	584.5	600.5	612.5
600	573.5	591.0	607.0	619.0
800	580.0	598.0	614.0	626.0
1000	587.0	605.0	620.5	632.5
1200	593.5	611.5	627.5	639.5
1400	600.5	618.5	634.5	646.5

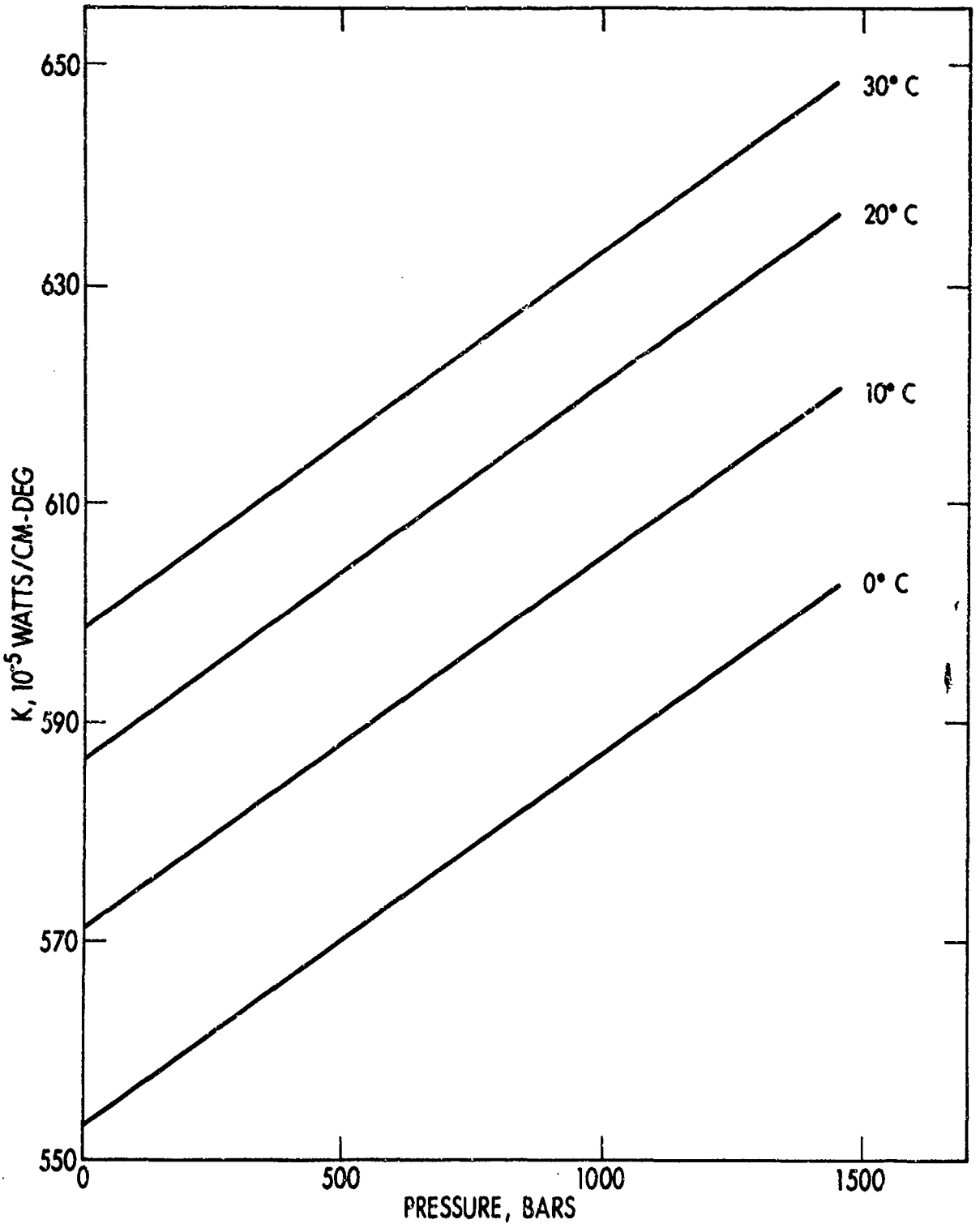

Figure 2 - Thermal Conductivity of Standard Sea Water as a Function of Pressure as Determined from Equation 1 at Various Temperatures

DISCUSSION

Investigation of the basic properties of sea water has been neglected for many years. However, with the recent upsurge of interest regarding maximum utilization of all our natural marine resources has emerged the realization that we lack much basic knowledge concerning the properties of sea water for engineering design. These experiments are an excellent case in point.

While interest in the thermal conductivity of pure water has attracted 30-odd investigators over the last 50 years, we could not find one researcher who developed a similar interest in sea water.

Since there have been no direct measurements of K for sea water, educated guesses about its value were advanced as early as 1907 by Krummel.[4] He assumed that thermal diffusivity (the thermal conductivity divided by the product of density and the specific heat) is approximately the same for both fresh water and sea water. Using this proposition, Barrett and Nettleton[5] computed K at 17.5° C for sea water during their compilation for the International Critical Tables. The value they gave for 35 o/oo salinity is 5.58×10^{-5} watts/cm-deg. We obtain a value of 5.83×10^{-5} watts/cm-deg from equation (1). The discrepancy of 4.5%, we believe, can be traced to the invalid assumption previously noted.

Currently accepted values are based upon the investigations of Riedel,[6] who compiled a table of molar conductivities for ions in aqueous solution at 20° C and 1 atmosphere. These contributions are utilized with the equation

$$K_{sol} = K_{H_2O} + \sum a_i c_i$$

where:

K_{sol} = thermal conductivity of the solution

K_{H_2O} = thermal conductivity of water

a_i = molar thermal conductivity of the ion

c_i = molar concentration of the ion.

Using values for the major ions in sea water indicates a decrease in the thermal conductivity on the order of about 3×10^{-5} watts/cm-deg (for 35‰ salinity) over that for pure water at atmospheric pressure. Based upon our previously reported values for pure water,[3] we observe a decrease of from 4.5 to 10.0 x 10^{-5} watts/cm-deg from 0° to 30° C.

However, it should be mentioned that the difference between these calculated values and those measured experimentally is hardly greater than 1% in the worst case.

Historical accounts of the effects of pressure on K for sea water are nonexistent, even on a theoretical basis. Our results indicate that the thermal conductivity of sea water increases only about 80% as fast as does the K for water for a similar pressure increase. This is a most unexpected result and might be related to less rapid increase in density for sea water compared to pure water.

CONCLUSIONS

- The thermal conductivity of sea water is a direct function of pressure and temperature throughout the range studied.

- Currently accepted values for the thermal conductivity of sea water at atmospheric pressure may not be in error by more than 1%.

- The effects of pressure on the thermal conductivity of sea water are less than expected on the basis of values for fresh water.

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